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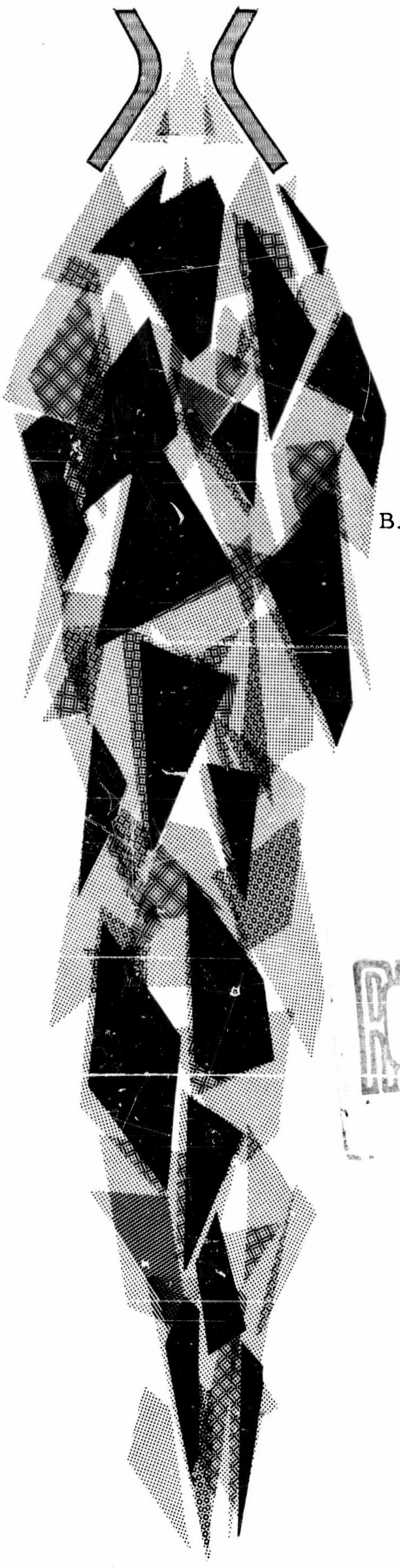

REPORT NO. S-94

BALLISTIC SCALE-UP OF NF PROPELLANTS

I. 80-lbm Motor Demonstration Firing (U)

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Report No. S-94

BALLISTIC SCALE-UP OF NF PROPELLANTS
I. 80 lbm Motor Demonstration Firing (U)

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BALLISTIC SCALE-UP OF NF PROPELLANTS

I. 80-lbm Motor Demonstration Firing

ABSTRACT

Production of an NFPA/TVOPA propellant having a new prepolymer binder system was scaled up from gram to multipound batches in six months. Ballistic scaling data on RH-SE-103cf were obtained in motors ranging in size from 10 grams to 80-lbm during this time. The burning rate was 0.97 in/sec at 1000 psia and the pressure exponent was 0.6. A specific impulse (I_{sps}) of 261.3 lbf-sec/lbm (97% of theoretical) was obtained from the 80-lbm motor firing.

The radar attenuation properties of RH-SE-103 (NF) and RH-P-112 (PNC) exhaust plumes were compared by measurements made about 1-foot and 5-feet from the nozzle exit planes. The X-band attenuation at the 1-foot measurement station was about 1.23 db for the high-energy NF propellant compared with 5.84 db for the PNC propellant.

In a preliminary study of techniques for evaluating possible toxicity hazards, samples of exhaust gases from the 80-lbm motor were obtained for HF analysis using evacuated stainless-steel bottles.

A polyester-based liner material which had been used with previous NF propellants was also satisfactory for the new system. Propellant would not bond well to fully-cured liner, but excellent bonds were obtained when the propellant was cast on partially-cured lin

ACKNOWLEDGEMENTS

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Laboratory batches of propellant were provided by Mr. Paul Gehlhaus of the Propellant Research Group.

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Mechanical Property data were provided by Dr. A. J. Ignatowski of the Applied Mechanics Group.

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BALLISTIC SCALE-UP OF NF PROPELLANTS

I. 80-lbm Motor Demonstration Firing

1. INTRODUCTION

A previous report (1)[1] discussed the ballistic characteristics of NF propellants whose binders were prepolymers of NFPA[2] and HPMA[2] crosslinked with HMDI[2]. The ballistics and processing of propellants based on this binder (designated RH-SB) were extensively investigated, and the maximum-impulse formulation, RH-SB-103, was scaled-up to a nominal 20-lbm motor. Although grains or cubes of this propellant were known to fissure in a relatively short time at elevated temperatures, the investigation was completed since modification to the binder involving only the copolymer and/or crosslinker would not be expected to affect processing or ballistics significantly.

Contractual agreements required the firing of a motor containing a nominal 80-lbm propellant grain by November 1965. The marginal properties of the SB system together with promising results of laboratory prepolymer studies prompted a decision in June 1965 to change binders before the 80-lbm motor was cast. The new binder (designated RH-SE) was a copolymer of NFPA and acrylic acid crosslinked with an epoxide. The technology was brought along as rapidly as possible with the first pilot plant batch being produced late in June, and the first micro-motors containing RH-SE-103 (a propellant formulation similar to RH-SB-103) being fired in August. Larger pilot batches were made,

[1]Parentheses indicate references listed at end of report.
[2]These and other acronyms are identified in the Glossary (Appendix A).

materials stockpiling began, and in October the first 2-inch diameter motors were fired. Scale-up to 6-inch diameter hardware was accomplished in November, and the effort culminated in the successful firing of the 80-lbm motor containing RH-SE-103cf on November 19, 1965.

This report presents the ballistic data obtained in a six-month program during which processes for making raw materials and propellant were scaled from gram to multipound batches.

2. COMPARISON OF SA, SB, AND SE PROPELLANTS

The binder for the first NF propellants made at these Laboratories was NFPA which was completely polymerized after casting by free radical initiation (2). This propellant was designated RH-SA-. The SA formulations specified concentrations of all components except the curing agent, since the amount of curing agent was always very small and could vary slightly, depending upon the polymerization characteristics of a given lot of NFPA. As the prepolymers were substituted for NFPA monomer in the SB and SE propellants, their recipes were kept similar to their SA analog (Table I) (3). This designation procedure is convenient but might imply that SA, SB, and SE propellants should give equivalent performances; however, the binders are significantly different from each other (Table II). SE-103 currently contains much more inactive ingredients (comonomer and curing agents) than either SA-103 or SB-103, and the specific impulse suffers accordingly (Table III).

Table I

Comparison of RH-SA, SB, and SE Recipes

	SA-103 Wt. %	SB-103 Wt. %	SE-103 Wt. %
NFPA Monomer	13		
NFPA/HPMA Prepolymer		13	
NFPA/AA Prepolymer			13
Ammonium Perchlorate[a]	46	46	46
Aluminum[b]	15	15	15
TVOPA	26	26	26
Curing Agent (added)			
Free Radical Initiator	~0.1		
Isocyanate Crosslinker		~0.4	
Epoxide Crosslinker			~2.1

[a] The ammonium perchlorate particle size is denoted by a two-letter suffix; for example, cf is 55μ and cd is 35μ.
[b] Alcoa 140.

Table II

Comparison of Binders for SA, SB, and SE Propellants

(Percentages Based on Total Propellant)

	SA-103 Wt. %	SB-103 Wt. %	SE-103 Wt. %
TVOPA	26.0	25.9	25.5
NFPA	13.0	11.7	12.0
HPMA	---	1.3	---
Acrylic Acid	---	---	0.7
Curing Agent	~0.1	0.4	2.1
Total Inerts	~0.1	1.7	2.8

Table III

Comparison of Theoretical Specific Impulse of SA, SB, and SE Propellants

	SA-103	SB-103	SE-103
Total Inerts (wt. %)	~0.1	1.7	2.8
I^0_{sps} (lbf-sec/lbm)	270.9	269.5	268.8

3. LINER STUDIES

Liners had been successfully developed for both the SA (vinyl/free-radical cure) and SB (hydroxyl/isocyanate cure) binder systems. The SE propellant presented still another type of curing chemistry (carboxyl/epoxide cure) for which a liner was needed. Screening tests showed that LR6-73 (Table IV) provided good bonding for the SE propellants as well as for SB and SA.

Table IV

LR6-73 Liner Formulation

Component	Wt. %
Paraplex® P-13[a]	35
Paraplex® P-43[a]	35
7TF-1 Asbestos[b]	30
Lupersol DDM®[c] (curing agent)	1 (added)

[a]Rohm and Haas Company, Philadelphia, Pennsylvania.
[b]Johns-Manville, New York, New York.
[c]Wallace and Tiernan Corp., Newark, New Jersey.

Bond strengths exceeding the tensile strength of the propellant were obtained with all three binders, but with SB and SE the liner could not be completely cured before casting of propellant (Table V). A cure time of less than 6 hours at +140°F provided good results for the SE binder (Table VI).

Table V

Comparison of Bond of SE, SB, and SA Propellant

Completely-Cured LR6-73

Propellant	Cure Time (hr)	Cure Temp. (°F)	Bond Strength (psi)	Remarks
RH-SA-103	24	140	30	Good propellant bond
RH-SB-103	24	140	0	No propellant bond
RH-SE-103	24	140	0	No propellant bond

Table VI

Effect of Liner Cure Time on Bond of SE-103 to LR6-73

Cure Time (hr.)	Cure Temp. (°F)	Bond Strength (psi)	Type Failure
>100	+140	0	Propellant bond
24	+140	0	Propellant bond
6	+140	46	Cohesive propellant
4	+140	48	Cohesive propellant
2	+140	38	Cohesive propellant
0	N/A	40	Cohesive propellant

The necessity of using a partially cured liner presented a problem in casting the 80-lbm motor because it was cast from two different propellant batches and held at +100°F between castings. Tests were run to simulate the incremental casting with an expected holding time of 6 to 8 hours. The results indicated that no problem in bonding should occur (Table VII). As yet there is no completely satisfactory explanation for the effects of liner cure time on the bond of SE-propellant to LR6-73.

Table VII

Results of Tests to Evaluate Effect of Holding at 100°F on Bond of Propellant to Liner

Assembly No.	Liner and Propellant Cure History	Bond Results
1 (Simulates first half of motor)	Liner: Overnight at ambient; two hrs. at +100°F prior to casting. Propellant: Cast, held at +100°F six hrs. prior to normal cure at +140°F	Good bond on all samples. Average pull strength of 74 psig.
2 (Simulates last half of motor)	Liner: Overnight at ambient; Eight hrs. at +100°F prior to casting. Propellant: Cast, placed at +140°F immediately for normal cure.	Good bond on all samples. Average pull strength of 77 psig.

4. MOTOR SCALE-UP

4.1 Micro-Motor Firings of RH-SE-103cf

Early evaluation of limited quantities of propellant ingredients was accomplished with the 10-gram .75C.50-1.5[1] test motor using previously established techniques (4). The ballistic properties of RH-SE-103cf were close to those of RH-SB-103cf, except that the additional inert ingredients reduced the burning rate slightly. RH-SB-103cf burned at 1.15 in/sec at 1000 psia, while RH-SE-103cf burned at 0.97 in/sec at the same pressure. A summary of all micro-motor data obtained in this program is presented in Table VIII and Fig. 1.

[1]This system of designating motor sizes indicates a 0.75-inch O.D., a 0.50-inch I.D., and a length of 1.5 inches.

Table VIII

Summary of Ballistic Data for RH-SE-103 Obtained in 0.75C.5-1.5 Micro-Motors

Round No.	Batch No.	K_n	$\overline{P}_{eq}$ (psia)	$\overline{P}_b$ (psia)	$\overline{r}_b$ (in/sec)	$P_{max}/\overline{P}_b$	$\int P_b dt/\int P_{tot} dt$	I_{spd} (lbf-sec/lbm)	I_{sps} (lbf-sec/lbm)
4853	08[a]	66.3	404	404	0.58	1.18	0.96		
4854		82.7	680	671	0.75	1.21	0.97		
4855		110.7	1337	1280	1.15	1.09	0.90		
4856		127.1	1830	1766	1.32	1.10	0.94		
4993	1004[b]	76.7	840	790	0.93	1.19	0.96		
4994		64.4	521	514	0.76	1.13	0.95		
4995		89.8	964	933	1.04	1.17	0.93		
4996		109.7	1716	1543	1.33	1.16	0.97		
4998		72.5	693	665	0.83	1.14	0.97		
4989		87.3	1015	964	1.02	1.15	0.97	246.0	250.8
4990		91.8	1065	1044	1.09	1.11	0.97	250.6	254.9
4991		91.6	1062	1041	1.13	1.09	0.94	249.6	254.4
4992		90.2	1053	1025	1.12	1.22	0.95	249.8	255.0
4997		90.8	1103	1058	1.13	1.11	0.96	249.5	253.8
								Average	253.8
5103	1016[a]	83.0	733	725	0.79	1.14	0.98		
5104		116.4	1752	1703	1.34	1.11	0.96		
5105		94.3	973	950	0.99	1.09	0.95	249.6	256.4
5106		94.5	1002	978	0.99	1.13	0.97	249.2	255.0
5107		95.0	1009	986	0.98	1.13	0.97	251.5	256.8
								Average	256.1
5192	1020[a]	67.4	466	463	0.61	1.10	0.98		
5191		80.9	781	765	0.81	1.14	0.97		
5190		95.7	1097	1060	0.99	1.11	0.96		
5193		108.8	1451	1391	1.25	1.14	0.89		
5194		114.6	1577	1535	1.21	1.07	0.97		

[a] cf grind APC
[b] cd grind

4.2 Results of 2-inch Motor Firings

As more propellant became available, 2C1.5-4.0 test motors containing 150-gm. of propellant were fired to give information on ballistic scale-up effects in motors and also on process scale-up. As expected, there was no increase in burning rate (Table IX, Fig. 2).

Using the 255.6 lbf-sec/lbm value of I_{sps} from the 2C1.5-4.0 motor, specific impulse values of 258.6 and 261.7 lbf-sec/lbm were predicted for the 6C5-11.4 and 80-lbm motors, respectively, using well-established techniques.(4).

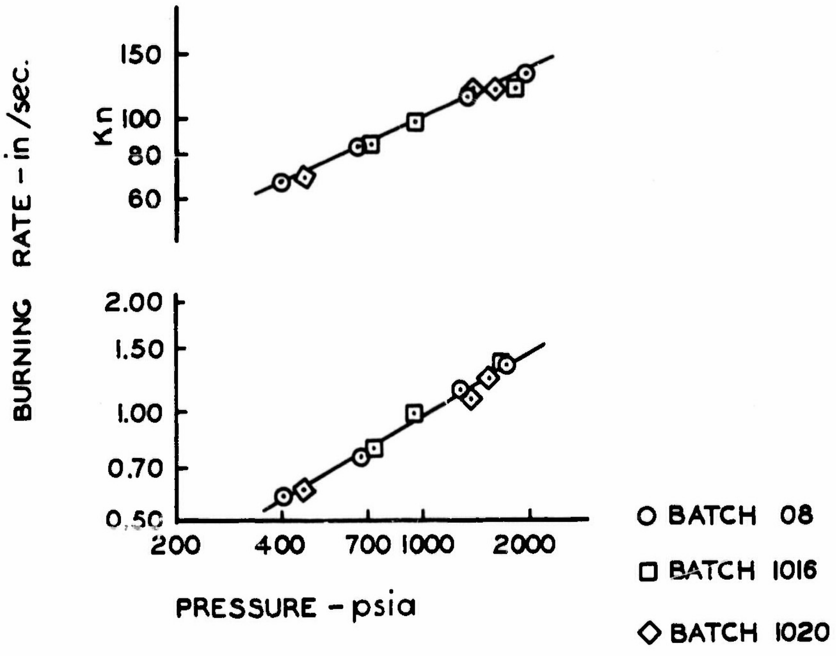


FIG. 1 P-K-r DATA FROM MICRO-MOTORS FOR RH-SE-103cf.

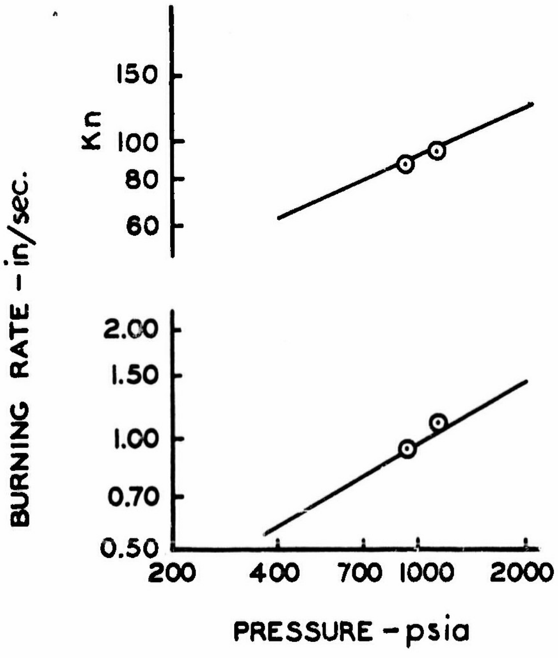


FIG. 2 COMPARISON OF P-K-r DATA FROM 2 X 4 MOTORS WITH LINES DRAWN FROM MICRO-MOTOR DATA.

Table IX

Summary of Ballistic Data for RH-SE-103cf Obtained in 2C1.5-4.0 Motors

Round No.	Batch No.	K_n	$\overline{P}_b$ (psia)	$\overline{r}_b$ (in/sec)	$P_{max}/\overline{P}_b$	$\int P_b dt / \int P_{tot} dt$	I_{spd} (lbf-sec/lbm)	I_{sps} (lbf-sec/lbm)
5108	1016	96.4	1009	0.97	1.06	0.98	251.8	256.7
5109		95.7	1048	0.99	1.05	0.98	252.5	256.6
5110		97.4	1124	1.10	1.04	0.96	254.9	258.5
							Average	257.2
5195	1020	92.8	942	0.94	1.04	0.98	248.9	254.8
5196		92.5	943	0.94	1.04	0.97	249.3	255.3
5197		90.9	938	0.94	1.42	0.98	250.4	256.7
							Average	255.6
5209	1021	95.8	990	0.97	1.04	0.98	250.8	258.0
5208		96.9	1057	1.01	1.05	0.98	250.6	255.1
5206		96.3	978	0.94	1.20	0.98	249.0	254.7
5207		95.7	971	0.94	1.14	0.97	250.7	256.2
							Average	255.5
5267	1025	93.9	943	0.92	1.24	0.97	251.1	257.4
5268		93.9	931	0.91	1.24	0.97	250.3	257.0
5169		94.2	938	0.95	1.20	0.95	248.2	255.4
5270		94.1	941	0.91	1.13	0.98	259.9	259.9
							Average	257.4

4.3 Results of 6-inch Motor Firings

Two 6C5-11.4 test motors were fired to check the specific impulse predictions and the propellant ballistics before casting the 80-lbm motor. Burning rates agreed well with previous data and the measured value of I_{sps} (258.6 lbf-sec/lbm) agreed precisely with the predicted value (Table X, Fig. 3). Microwave attenuation data are reported in Section 5.4.3.3.

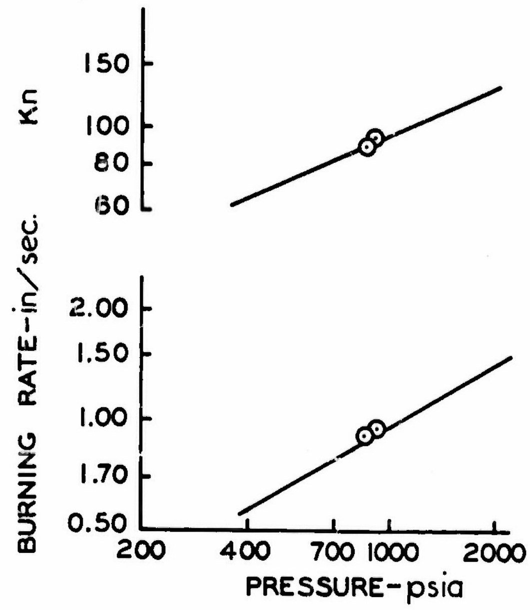


FIG. 3 COMPARISON OF P-K-r DATA FROM 6 X 11.4 MOTORS WITH LINES DRAWN FROM MICRO-MOTOR DATA.

5. RESULTS OF 80-lbm MOTOR FIRING

5.1 Motor Description

The motor case of the 5KS4500 Jato[1] with a case-bonded, cylindrically perforated grain 5.5-inches in diameter has been used as a standard large-scale specific impulse comparison motor in several propellant evaluation programs (5). This motor has a nominal charge weight of 100 lbm. and has a surface progressivity ratio of 1.54. In order to reduce both the progressivity ratio and the amount of propellant required, a cylindrical grain 6.5-inches in diameter was designed for use with RH-SE-103cf. The dimensional characteristics of the 80-lbm motor grain are recorded in Table XI and Fig. 4 is a drawing of the firing assembly. The 80-lbm motor is also designated 9.1C6.5-41.

[1]Unit No. 211 in the SPIA M-1 Rocket-Motor Manual.

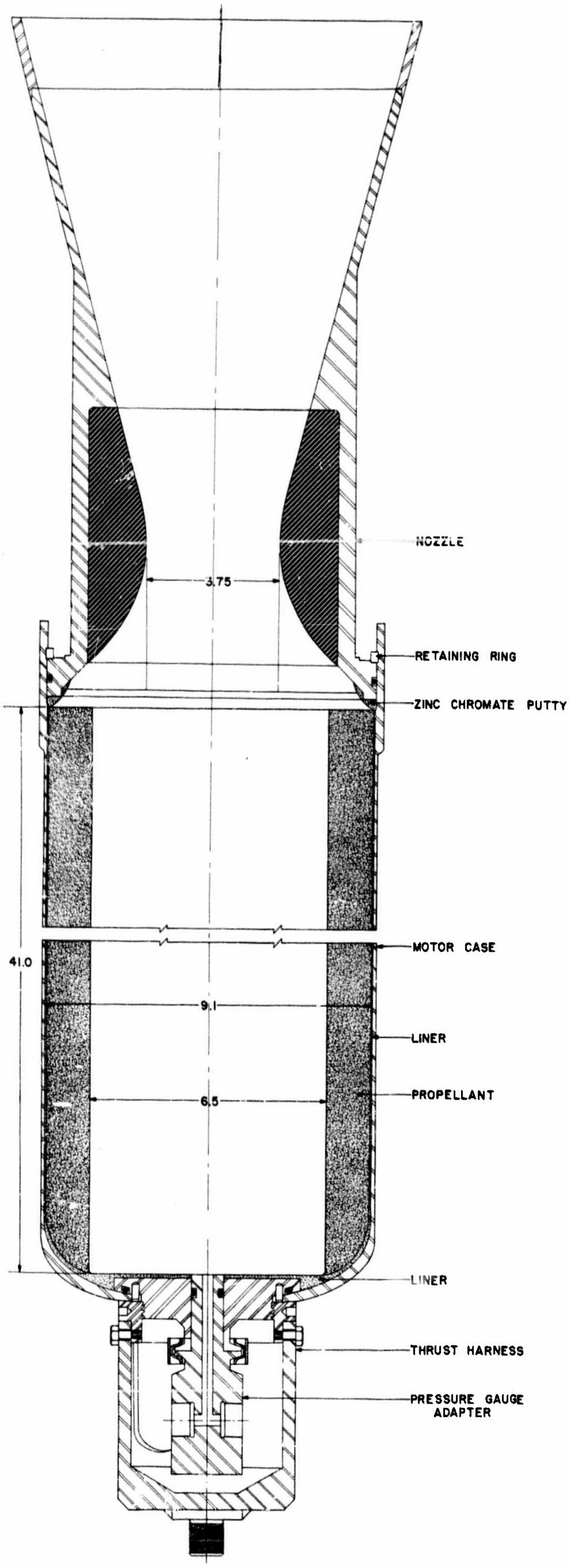


FIG. 4 9C6.5-40 STATIC TEST MOTOR (80-lbm MOTOR) FIRING ASSEMBLY.

Table XI

Characteristics of 80-lbm Motor (9.1C6.5-41)

Grain Dimensions	
Initial length (in)	41.5
Final length (in)	38.7
Average length (in)	40.2
Outside diameter (in)	9.1
Inside diameter (in)	6.5
Initial surface area (in^2)	884
Final surface area (in^2)	1096
Ratio of final to initial surface	1.24
Grain volume (in^3)	1261

5.2 Results From Checkout Rounds

Two 9.1C6.5-41 motors were cast with RH-P-112cf, a well-characterized propellant, to check out lining, processing, handling, firing, and data acquisition before the NF round was made.

5.2.1 Lining Procedure

The liners for plastisol and NF propellants were mixed manually in a disposable carton with a spatula. The resins and curing agents were blended thoroughly before the fillers were added. Mixing continued until the material was smooth and uniform.

The liners were applied to the interior of the case through the use of a manually-operated sweep blade (Fig. 5). The motor and sweep assembly was clamped vertically, and the liner was applied to the case wall with a spatula at the aft end of the motor. As the sweep blade rotated, the liner rolled ahead of the blade and spiralled down to the head end of the motor. This technique worked equally well with the liners for plastisol and NF propellants.

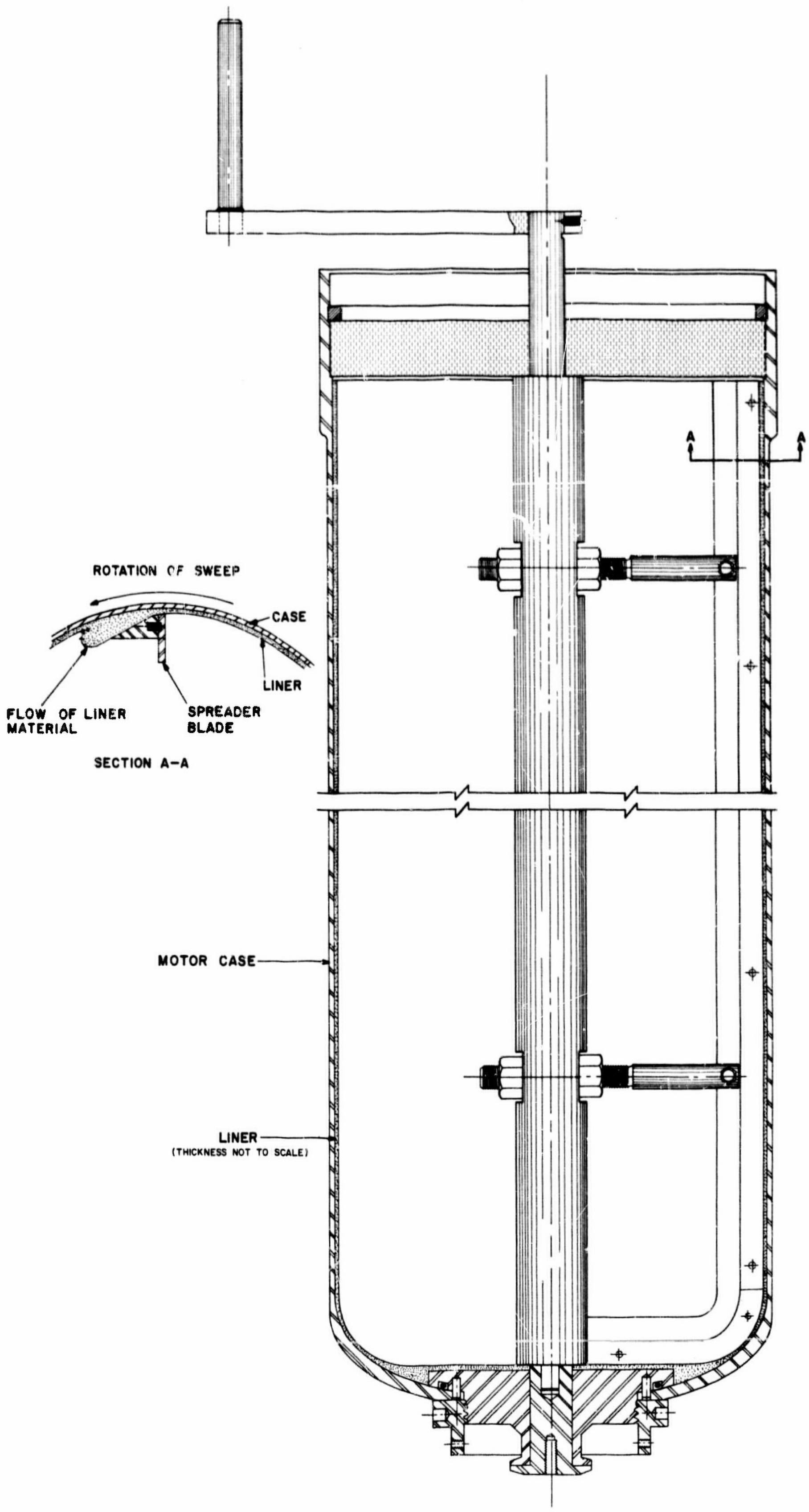


FIG. 5 LINER SPREADER ASSEMBLY FOR 80-lbm MOTOR.

5.2.2 Casting Technique

Plastisol propellants were mixed in a 10 gallon turbine mixer and NF propellants were mixed in a 5-gallon Baker-Perkins vertical planetary-action mixer. Mixing and casting were both done remotely, with the casting progress being monitored by a digital readout of propellant weight and also by closed-circuit television. When the necessary amount of propellant had been cast, the mandrel was inserted remotely. Casting operations are similar whether the motor contains 10 grams or 100 pounds; no processing problems were encountered.

5.2.3 Ballistic Results from Checkout Rounds

The motors performed as predicted (Table XII). Microwave attenuation measurements made for comparison with the results from the NF round are reported in Section 5.3.3.3.

Table XII

Ballistic Summary From 9.1C6.5-41 System Check Rounds Containing RH-P-112cf

	Results		
	Round 5218	Round 5274	Prediction
Grain weight (lbm)	73.9	74.1	74
Burning time (sec)	2.16	2.04	2.2
Burning pressure (psia)	1013	1006	1000
Burning rate (in/sec)	0.61	0.61	0.63
Action time (sec)	2.16	2.19	---
Action pressure (psia)	986	972	---
Maximum pressure (psia)	1200	1169	1200
Initial pressure (psia)	824	833	784
P_f/P_i	1.46	1.40	1.5
Average thrust (lbf)	8088	8052	8300
Maximum thrust (lbf)	10,211	10,035	
Discharge coefficient (lbm/lbf-sec)	0.0063	0.0063	0.0063
I_{tot} (lbf-sec)	17,906	17,982	
I_{spd} (lbf-sec/lbm)	242.3	242.3	
I_{sps} (lbf-sec/lbm)	246.3	247.5	

5.3 Production History of 80-lbm NF Motor

5.3.1 Processing Conditions

The 9.1C6.5-41 motor was lined with LR6-73 and kept at +80°F overnight before being sent to the pilot plant for casting. The motor was set up and placed at +100°F at 9:00 a.m. The first batch of propellant was cast at 1:00 p.m. and the motor was maintained at +100°F while the next batch was mixed. The second batch was cast at 8:00 p.m. and the motor was cured for 40 hours at +140°F.

5.3.2 Quality Control

5.3.2.1 Liner Bond Check

As a check on the propellant bonding, case-bond specimens were prepared from the same liner batch used in the motor and were kept with the motor until propellant cure was completed. Half of the case-bond specimens were cast with the first batch and the other half were cast with the second batch. These specimens were a final check of the effect of extended liner cure at elevated temperature as well as a specimen check of the liner batch. The results showed a substantial decrease in bond strength between the first and second castings (Table XIII). These results did not contradict those of the earlier tests since the total time at +100°F was 3 hours longer than had been tested previously; however, the results did emphasize the need for additional liner research for the NF propellant system. The bond was sufficient for the simple, thin-webbed cylindrical geometry, so the tests did not influence the decision to fire the 80-lbm motor.

Table XIII

Results from Case Bond Specimens Cast Concurrently with 80-lbm Motor

Assembly No.	Avg. Bond Strength (psi)	Bond Results
1 (Cast with propellant from the first batch)	39	The breaks occurred partially in the propellant and partially in the propellant bond.
2 (Cast with propellant from the last batch)	17	All breaks occurred in the propellant bond.

5.3.2.2 Grain Quality Determinations

Both visual and x-ray inspections showed the grain quality and the case bond to be good. Only one $\frac{1}{16}$-inch diameter void was found in the entire grain. Most important, the liner-propellant bond was checked manually and the aft end of the grain was bonded firmly to the case.

5.3.2.3 Propellant Ballistics Check

Four 2C1.5-4.0 motors were obtained from the first batch and fourteen 2C1.5-4.0 motors were cast from the second batch of propellant cast in the 80-lbm motor for a final propellant quality check. Four rounds from each batch were fired before the 80-lbm motor was prepared for firing. The results were typical of results obtained from similar tests of other batches. The reproducibility was excellent (Table XIV). Ten motors were placed in storage at ambient temperatures to obtain surveillance data.

Table XIV

Ballistic Results from 2C1.5-4.0 Batch Check Motors

Round	Batch	K_n	$\overline{P}_b$ (psia)	$\overline{r}_b$ (in/sec)	$\int P_b dt / \int P_{tot} dt$	I_{sps} (lbf-sec/lbm)
5315	1026	92.4	910	0.892	0.98	256.3
5316	1026	97.0	1006	0.973	0.96	256.1
5317	1026	96.1	959	0.924	0.98	256.0
5318	1026	94.5	933	0.915	0.98	255.4
					Average	256.0
5319	1027	94.1	964	0.942	0.97	256.8
5320	1027	95.1	970	0.942	0.98	255.4
5321	1027	96.4	1012	0.958	0.98	256.1
5322	1027	94.3	927	0.955	0.94[a]	254.5[a]
					Average	256.1
					Overall Average	256.0

[a]Left out of average.

5.3.2.4 Propellant Mechanical Properties Check

Quality control specimens from each batch were tested, and again results were typical of previous tests (Table XV).

Table XV

Mechanical Properties for RH-SE-103cf, Batches 1026 and 1027

Batch	Max. Stress (psia)/Strain at Max. Stress (%) -40°F	+77°F	Specific Gravity
1026	680/12	82.4/24	1.80_4
1027	672/12	83.4/22	1.80_4

5.3.3 Firing Results

The 80-lbm motor was successfully static tested at Rohm and Haas F Range on November 19, 1965. Instrumentation included two pressure channels, two thrust channels and three channels of microwave attenuation data. Photographic records were obtained with two high-speed motion analysis cameras and one normal speed camera. Five vacuum bottles for sampling exhaust products were also used. All equipment functioned properly.

The specific impulse obtained from the 80-lbm motor firing was 261.2 lbf-sec/lbm which agreed well with the predicted value (Table XVI). The pressure-time history was smooth (Fig. 6) and the burning rate agreed with the previous pressure-burning rate correlation (Fig. 7). The pressure was lower than anticipated because the nozzle throat size was based on early P-K-r data from micro-motors and an allowance for some scaling (reduction) of discharge coefficient with motor size increase was made. No such scaling was found (Table XVII).

Table XVI

Ballistic Summary from 9.1C6.5-41 80-lbm Motor Containing SE-103cf

	Results	
	Actual	Predicted
Grain wt. (lbm)	80.82	82±1
Burning Time (sec)	1.423	1.28
Burning Pressure (psi)	815	1000
Burning Rate (in/sec)	0.89	0.97
Action Time (sec)	1.527	
Action Pressure (psia)	790	
Maximum Pressure (psia)	926	1200
Initial Pressure (psia)	678	700
P_f/P_i	1.37	1.71
Average Thrust (lbf)	12,971	15,000
Maximum Thrust (lbf)	15,847	19,000
Discharge Coefficient	0.0060	0.0057
I_{tot} (lbf-sec)	20,309	
I_{spd} (lbf-sec/lbm)	251.4	
I_{sps} (lbf-sec/lbm)	261.2	261.7

Table XVII

Effect of Motor Size on Discharge Coefficient

Motor Size	C_D (lbm/lbf-sec)
0.75 × 1.5	0.00606
2 × 4	0.00601
6 × 11.4	0.00602
9.1 × 41	0.00604

5.3.4 Results of Exhaust Sampling Tests

During the 80-lbm motor firing, samples of gas in the exhaust area were obtained in stainless steel vacuum bottles. The bottles were installed at the locations shown in Fig. 8 at approximately the same elevation as the motor. Electric valves were used in conjunction with the range timer to open the bottles 200 msec after motor ignition. The valves stayed open 2.50 sec. (motor action time was 1.42 sec.) during which time the pressure in the bottles increased

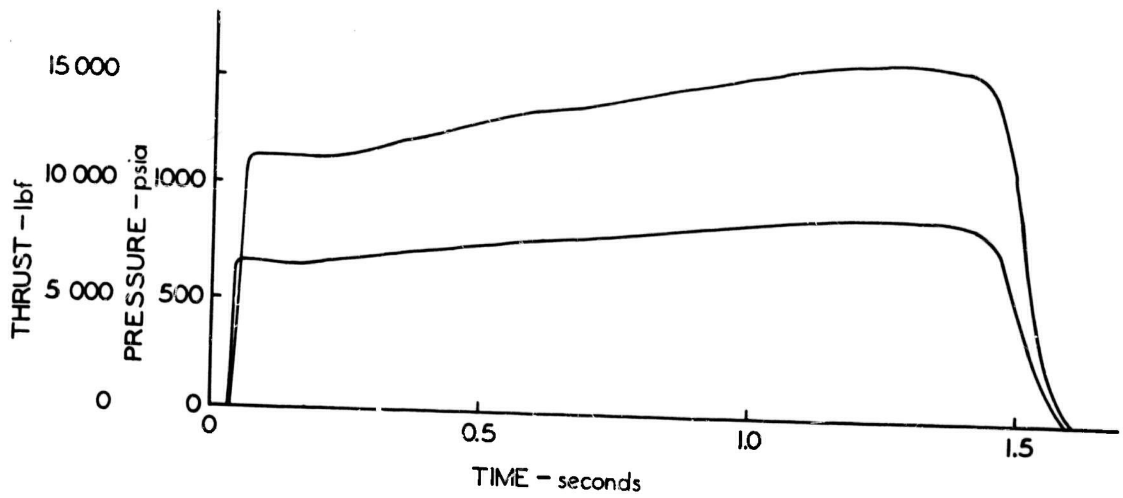


FIG. 6 PRESSURE- AND THRUST-REPLOTS FROM 80-lbm MOTOR CONTAINING RH-SE-103cf PROPELLANT.

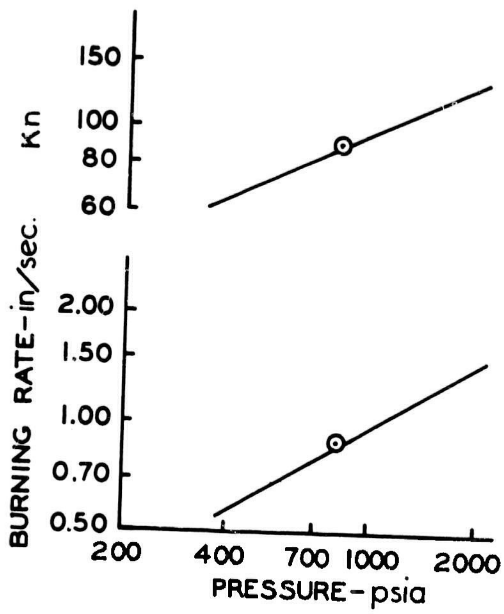
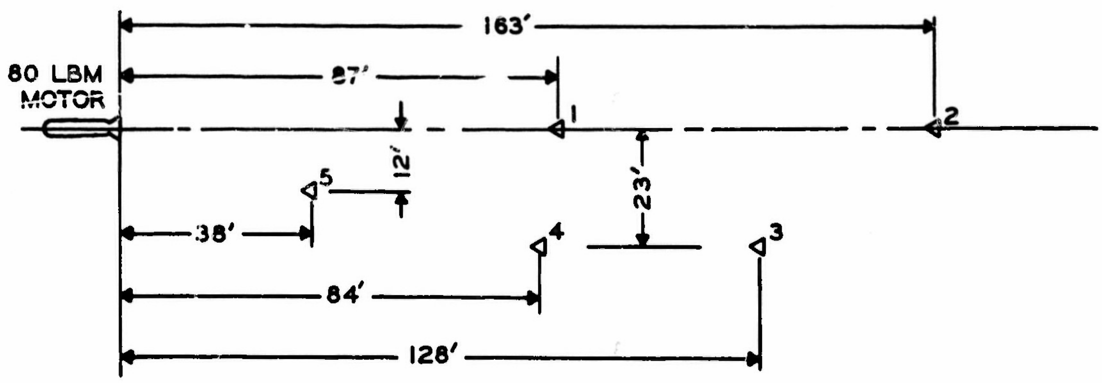


FIG. 7 COMPARISON OF P-K-r DATA FROM 80-lbm MOTOR WITH LINES DRAWN FROM MICRO-MOTOR DATA.



SAMPLE LOCATION	PPM HF	Mg/M³ HF
1	983	834
2	435	369
3	274	232
4	73	62
5	40	34

FIG. 8 PLAN VIEW OF SAMPLE LOCATIONS FOR 80-lbm NF MOTOR TOXICITY TEST.

from 1 mm mercury to 602 mm mercury. The results of the sample analyses were converted to parts per million of HF and to milligrams of HF per standard cubic meter. The measured HF concentrations are shown by location in Fig. 8. A similar analysis performed on test bottles charged with a known HF concentration indicated that the technique used yielded only 33% recovery of HF; therefore the concentrations shown in Fig. 8 may be only one third as high as actually existed. Thermo-chemical calculations of the exhaust gas composition give a concentration of 180, 900 ppm HF at the nozzle exit.

These tests were primarily to determine the feasibility of using the sampling technique in future studies of the toxicity problems associated with rocket exhausts. Several problems were revealed in these preliminary tests; for example, the low recovery of HF was mentioned above. A second difficulty was that the amount of air dilution occurring because of improper valve sequencing cannot be

separated from the normal mixing of the exhaust gases with air. Multiple sample bottles at each sampling point sequenced to open at different times would be a means by which this problem could be eliminated.

5.3.5 Results of Microwave Attenuation Tests

Radar attenuation measurements were made on plastisol nitrocellulose and NF type propellants in both 6C5-11.4 and 9.1C6.5-41 static test motors using previously established techniques (6). Round identification and pertinent physical measurements including radar antennae locations are given in Table XVIII.

Table XVIII

Test Data for Attenuation Measurements

Round Number	Propellant Composition	Motor Designation	$\overline{P}_b$ (psia)	XR	D_e (in.)	Distance from Nozzle Exit (inches) Upstream	Downstream
5271	RH-P-112	6C5-11.4	906	7.29	3.19	10.25	67.8
5272	RH-P-112	6C5-11.4	880	7.89	3.32	10.25	67.8
5273	RH-SE-103	6C5-11.4	896	8.99	4.83	7.50	67.5
5274	RH-P-112	9C6.5-43	1003	7.43	7.22	10.0	67.5
5323	RH-SE-103	9C6.5-43	819	9.00	11.25	11.25	56.0

The test results (Table XIX) show that the RH-SE-103 (NF composition) nozzle exit attenuation is a factor of three or more less than for plastisol nitrocellulose composition RH-P-112. The lower attenuation of RH-SE-103 at the upstream station was significant since RH-SE-103 has a higher exhaust temperature than does RH-P-112. The lower attenuation probably results from a higher collision frequency between free electrons and other species in the NF exhaust. The higher collision frequency is evidenced by the small differences between the attenuation levels at the X and K_a frequencies.

Table XIX

Radar Attenuation Measurements for RH-P-112 and RH-SE-103 Propellants

Round No.	Propellant Composition	Ignition Time (sec)	Burning Time (sec)	Measurement Time (sec)	Attenuation in Decibels K_a Band[a] (Upstream)	X Band[b] (Upstream)	X Band[b] (Downstream)
5271	P-112	0.040	0.940	0.548	3.20	4.35	7.34
5172	P-112	0.024	0.930	0.548	2.55	4.34	7.00
5273	SE-103	0.030	0.596	0.356	0.73	0.69	4.99
5274	P-112	0.830[c]	3.000	2.004	4.73	5.84	8.03
5323	SE-103	0.828[c]	2.300	1.604	1.17	1.23	5.85

[a]Frequency 33 GHz
[b]Frequency 10 GHz
[c]Includes 0.805 sec. delay for camera starting.

At the downstream station, the attenuation level for the NF system was only 20-30% lower than that for the plastisol system (Table XIX). This is probably a result of a combination of two effects: (1) air entrainment and afterburning tend to decrease the difference in collision frequencies in the mixing and afterburning regions of the plumes and (2) kinetic energy recovery tends to decrease the difference in electron concentrations in the unmixed region of the plume.

6. RESULTS AND CONCLUSIONS:

The program demonstrated that large-scale production of NF propellants and ingredients is feasible. The smooth combustion, high energy, and good specific impulse efficiency of the NF propellants were demonstrated in an 80-lbm motor firing. The fact that a high-energy NF propellant has lower radar attenuation properties than many lower-energy systems was demonstrated. One possible method for sampling the atmosphere in the neighborhood of a rocket with toxic exhaust products was shown to be feasible.

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APPENDIX A

Glossary

I. Acronyms and Abbreviations

AA	Acrylic acid
HF	Hydrogen fluoride
HMDI	Hexamethylene diisocyanate
HPMA	Hydroxypropyl methacrylate
NFPA	2,3-bis(difluoramino)propyl acrylate
PNC	Plastisol nitrocellulose composite
TVOPA	1,2,3-tris[1,2-bis(difluoramino)ethoxy]propane

II. Symbols

C_D	Mass discharge coefficient (lbm/lbf-sec)
D_e	Nozzle exit diameter (in.)
I_{spd}	Delivered specific impulse (lbf-sec/lbm)
I_{sps}	Standard deliverable specific impulse (lbf-sec/lbm)
I^0_{sps}	Standard theoretical specific impulse (lbf-sec/lbm)
I_{tot}	Total impulse (lbf-sec)
K_n	Burning surface to throat area ratio
$\overline{P}_b$	Burning-time average chamber pressure (psia)
$\overline{P}_{eq}$	Equilibrium pressure for micro-motor (psia) (used for P-K correlation)
P_i	Initial chamber pressure (psia)
P_f	Final chamber pressure (psia)
P_{max}	Maximum chamber pressure (psia)
$\bar{r}_b$	Average linear burning (regression) rate of propellant (in/sec)

XR	Nozzle expansion ratio
$\int P_b dt / \int P_{tot} dt$	Ratio of burning pressure integral to total pressure integral

SUPPLEMENTARY

INFORMATION

ROHM AND HAAS COMPANY

REDSTONE RESEARCH LABORATORIES
HUNTSVILLE, ALABAMA 35807

March 22, 1966

To: Recipients of Rohm and Haas Reports

Subject: ERRATA for Report Number S-94

Table #10 of subject report was inadvertently omitted. All recipients of this report are requested to clip the table below and attach at bottom of page nine (9).

Table X

Ballistic Data for RH-SE-103cf Obtained in 6C5-11.4 Motors

Round No.	Batch No.	K_n	$\overline{P}_b$ (psia)	$\overline{r}_b$ (in/sec)	$P_{max}/\overline{P}_b$	$\int P_b dt / \int P_{tot} dt$	I_{spd} (lbf-sec/lbm)	I_{sps} (lbf-sec/lbm)
5217	1021	89.0	851	0.91	1.03	0.94	241.4	258.3
5273	1025	94.0	897	0.92	1.14	0.96	251.4	258.9
							Average	258.6